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Reduced Left-Hemisphere Lateralization of the Visual Word Form Area During Orthographic Processing in Adults with Developmental Dyslexia: A Secondary Lateralization Index Analysis

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Abstract

Background (including Aims):

Developmental dyslexia is a neurobiological learning disorder characterized by persistent difficulties in accurate and fluent word reading, affecting approximately 5–10% of the population. Neuroimaging studies have identified atypical activation in left-hemisphere reading regions, including temporoparietal, inferior frontal, and occipitotemporal cortices. However, whether dyslexia is specifically associated with altered hemispheric dominance within the reading network during distinct processing demands — particularly orthographic versus phonological — remains poorly understood. The present study constitutes an independent secondary analysis of publicly available task-fMRI data, with the aim of replicating and extending prior lateralization findings using an explicit statistical framework, and to examine brain-behavior relationships between fusiform lateralization and reading-related cognitive performance.

Methods

Data were obtained from OpenNeuro dataset ds005577, comprising Dutch-speaking adults with and without developmental dyslexia (N = 70; 35 dyslexia, 35 typically reading controls). Participants completed a rhyme decision task (phonological processing) and a lexical decision task (orthographic processing) during fMRI acquisition on a 3T scanner. Lateralization indices (LI) were computed for anatomically defined regions of interest (ROIs) within the reading network using the formula LI = (L − R) / (L + R), where L and R represent activated voxel counts in homologous left and right hemisphere ROIs at $p < 0.001$ (uncorrected). Group differences in absolute LI values were assessed using one-tailed independent samples t-tests with FDR correction (Benjamini-Hochberg, $q < 0.05$). Variability differences were assessed using Levene's test. Brain-behavior correlations between fusiform |LI| and standardized cognitive scores were examined using Pearson correlations.

Results

During phonological processing (rhyme task), no significant group differences in hemispheric lateralization were observed for any ROI (all $p > 0.09$, FDR-corrected). Both groups showed near-universal left-hemisphere dominance during phonological processing. During orthographic processing (lexical decision task), adults with dyslexia showed significantly reduced left-hemisphere lateralization of the fusiform gyrus/visual word form area (VWFA) compared to controls ($t(68) = 3.19$, $p = 0.001$, $d = 0.76$), a large effect. No other region reached significance. Adults with dyslexia also showed significantly greater variability in fusiform lateralization than controls (Levene's $F(1,68) = 10.20$, $p = 0.002$; DYS SD = 0.197, CON SD = 0.129). Across the full sample, fusiform lateralization correlated positively with word reading scores ($r = 0.39$, $p = 0.001$) and spelling ($r = 0.34$, $p = 0.005$), and negatively with phonological error rates ($r = -0.32$, $p = 0.008$).

Conclusions

These findings confirm that the primary locus of atypical hemispheric lateralization in developmental dyslexia is the VWFA during orthographic processing, and that this atypicality is characterized by increased individual variability rather than a uniform directional shift. Individual differences in VWFA lateralization are meaningfully linked to reading-related cognitive performance. These results replicate and extend prior work, supporting the VWFA deficit hypothesis of developmental dyslexia and highlighting the importance of examining both the magnitude and variability of hemispheric specialization in neuroimaging studies of reading disorders.

1. Introduction

Developmental dyslexia is one of the most common neurodevelopmental learning disorders, found in approximately 5–10% of all language and education systems [1, 2]. It is defined by unexpected and persistent difficulties in accurate and fluent word reading and spelling that may occur in the absence of sensory impairment, intellectual disability, or inadequate educational opportunity [3, 4]. The neurobiological basis of dyslexia is an active research area that reveals converging evidence pointing to atypical development and functional organization of the reading network in the left hemisphere.

The predominant cognitive theory of developmental dyslexia is the phonological deficit hypothesis (PDH), which proposes that the primary cognitive hallmark of the disorder is a deficit in phonological awareness — the conscious manipulation of the sound structure of spoken language [5, 6, 7]. It is believed that phonological difficulties interfere with learning grapheme-phoneme correspondences, explaining characteristic reading problems. This hypothesis has been broadly supported by behavioral studies in alphabetic languages such as Dutch [8, 9].

Neuroimaging studies have provided strong evidence of atypical structure and function of language areas in the left perisylvian cortex in developmental dyslexia. Consistently decreased activation in adults and children with dyslexia compared to typically-reading individuals has been found in three core regions during reading and phonological tasks: the left inferior frontal gyrus (IFG/Broca's area, regions BA 44/45), left temporoparietal cortex (supramarginal and angular gyri), and left occipitotemporal cortex, particularly the fusiform gyrus [10, 11, 12, 13, 14]. These hypoactivation results are corroborated by recent meta-analyses [13, 14], suggesting that the left occipitotemporal cortex shows the most consistent hypoactivation across studies and languages.

A region of particular interest within the left occipitotemporal cortex is the visual word form area (VWFA), located in the left fusiform gyrus (approximately MNI: −42, − 54, −12). The VWFA is thought to be specialized for the rapid, automatic, and language-independent recognition of written word forms [15, 16, 17]. It selectively responds to words and pseudowords rather than non-orthographic stimuli, and is closely related to reading fluency in skilled readers. Among the most replicated neuroimaging differences in dyslexia is hypoactivation of the VWFA in response to orthographic input, leading to

proposals that failure to specialize this pathway is a core neural difference underlying reading disability [12, 18, 13].

Studies of hemispheric laterality have further elucidated the atypical neural organization for reading in dyslexia. The reading network is progressively left-lateralized during typical reading development, and some studies have noted decreased or altered hemispheric specialization in individuals with dyslexia [12, 19]. Lateralization indices (LI) are a useful quantitative tool for describing hemispheric specialization in reading-related tasks [20, 21]. Decreased left lateralization in dyslexia may indicate weaker activation of left-hemisphere regions and greater engagement of right-hemisphere homologues, which are believed to serve less efficient whole-word or holistic reading strategies [12, 22].

Pérez-Cuesta et al. [23] directly examined hemispheric lateralization in the same public dataset analyzed here (OpenNeuro dataset ds005577), using a rhyme decision task and a lexical decision task. Their principal finding was an absence of group differences in lateralization for most regions, with a significant difference for the fusiform gyrus during the lexical decision task, indicating that adults with dyslexia showed reduced left-hemisphere asymmetry. They also reported greater intra-individual variability in the dyslexia group, suggesting that variability rather than a consistent directional shift may be a hallmark of atypical lateralization in dyslexia. The current study constitutes an independent secondary analysis using the same data, with the complementary aim of exploring brain-behavior relationships between fusiform lateralization and cognitive reading measures.

Despite prior work, several questions remain. The specificity of lateralization differences between phonological and orthographic processing demands has not been fully established within a single sample. Furthermore, the relationship between VWFA lateralization and reading-related cognitive performance has not been directly examined to a large extent. The present study aims to address these questions in a well-characterized Dutch-speaking sample, independently complementing the results of Pérez-Cuesta et al. [23].

2. Method

2.1 Participants

Data were obtained from OpenNeuro dataset ds005577, a publicly available task-fMRI dataset comprising Dutch-speaking adults with and without developmental dyslexia (DD). The sample consisted of 70 participants: 35 adults with developmental dyslexia (mean age = 19.7 years) and 35 typically reading controls (mean age = 20.1 years). All participants were right-handed native Dutch speakers with normal or corrected-to-normal vision. Dyslexia diagnoses were established prior to the study using standard psychoeducational assessment. Exclusion criteria included psychiatric disorders, neurological conditions, and contraindications to MRI. The study was carried out in accordance with the Declaration of Helsinki and approved by the ethics committee of the relevant institution.

2.2 Tasks and Stimuli

Rhyme Decision Task (Phonological Processing). Participants determined whether two visually presented words rhymed. This task required explicit analysis of word-forms and served as the primary measure of phonological processing. Rhyme decision trials constituted the experimental condition, while picture matching served as the control condition. Rest blocks provided an implicit baseline.

Lexical Decision Task (Orthographic Processing). Participants judged whether orthographically presented letter strings were Dutch words. This task required access to orthographic lexical representations and served as the primary measure of orthographic processing. Lexical decision was the experimental condition; line orientation discrimination served as the control condition. Rest blocks provided an implicit baseline. Both tasks used a block design. Full paradigm details are available at the OSF repository (https://osf.io/d8e9b/).

2.3 fMRI Data Acquisition

Functional MRI data were acquired on a 3T MRI scanner. Whole-brain BOLD signal was acquired using a T2*-weighted echo-planar imaging (EPI) sequence with a repetition time (TR) of 1.07 seconds. Full acquisition details are available in the dataset documentation on OpenNeuro (ds005577).

2.4 Preprocessing

Functional data were preprocessed using fMRIPrep version 23.2.1 [24]. Preprocessing steps included skull stripping, motion correction, susceptibility distortion correction, coregistration of functional to structural images, and normalization to MNI152NLin2009cAsym standard space. Spatial smoothing was applied using a 5-mm FWHM Gaussian kernel. Six motion parameters were included as nuisance regressors in the first-level general linear model.

2.5 First-Level GLM

Subject-level general linear models were estimated using SPM. Each task condition was modeled as a separate regressor convolved with the canonical hemodynamic response function. A 128-second high-pass filter was applied to remove low-frequency signal drift.

2.6 Lateralization Index Computation

Hemispheric lateralization was quantified using the lateralization index (LI) [20], computed for anatomically defined regions of interest (ROIs) within the reading network:

$LI = (L - R) / (L + R)$

where L and R represent the number of significantly activated voxels ($p < 0.001$, uncorrected) within homologous left and right hemisphere ROIs, respectively. LI values range from − 1 (fully right-lateralized) to + 1 (fully left-lateralized), with negative values indicating left-hemisphere dominance in this dataset's sign convention. Absolute LI values (|LI|) were used as the primary dependent variable to index the strength of lateralization independent of direction.

ROIs for the rhyme task included: Broca's area, precentral gyrus, supplementary motor area (SMA), middle temporal gyrus, and cerebellum. ROIs for the lexical decision task included: Broca's area, precentral gyrus, middle temporal gyrus, fusiform gyrus (VWFA region), inferior parietal lobule, and inferior occipital cortex.

2.7 Statistical Analysis

Group differences in absolute LI were assessed using one-tailed independent samples t-tests, with the directional hypothesis that controls would show greater left-hemisphere lateralization than adults with dyslexia. Multiple comparisons were controlled using the Benjamini-Hochberg FDR procedure at $q < 0.05$, applied separately within each task. Effect sizes were computed as Cohen's d. Group differences in LI variability were assessed using Levene's test for equality of variances. Brain-behavior relationships were examined using Pearson correlations between fusiform |LI| during the lexical decision task and standardized cognitive scores (spelling, phonological awareness, word reading) across the full sample and within groups separately. All statistical analyses were conducted in Python (scipy.stats).

2.8 AI-Assisted Writing

In the preparation of this manuscript, the authors used an AI language model (Claude, Anthropic) to assist with text editing, structural revision, and formatting in accordance with journal requirements. All scientific content, interpretations, and conclusions are the sole responsibility of the authors. The use of AI assistance is disclosed in accordance with the journal's AI policy (Section 8 of the Instructions for Authors).

3. Results

3.1 Rhyme Task — Phonological Processing

Lateralization indices during the rhyme decision task are summarized in Table 1 (see end of document). One-tailed independent samples t-tests revealed no significant group differences in the strength of left-hemisphere lateralization for any region of interest after FDR correction. Controls showed a trend toward stronger left-lateralization of the precentral gyrus compared to adults with dyslexia ($t(68) = 1.32$, $p = 0.095$, $d = 0.32$), as well as Broca's area ($t(68) = 1.18$, $p = 0.122$, $d = 0.28$) and the composite rhyme lateralization index ($t(68) = 1.32$, $p = 0.095$, $d = 0.32$), though none reached significance after correction. The middle temporal gyrus showed no directional difference ($t(68) = -0.81$, $p = 0.790$). Levene's tests indicated no significant group differences in LI variability for any rhyme task ROI (all $p > 0.12$). Both groups showed near-universal left-hemisphere dominance during phonological processing, with 100% of controls (35/35) and 94% of dyslexic adults (33/35) classified as left-lateralized based on the sign of the composite LI (Fisher's exact $p = .493$).

Table 1

Lateralization Index (|LI|) Group Comparisons — Rhyme Task (Phonological Processing). Values represent mean absolute lateralization index (SD). Higher values indicate stronger left-hemisphere lateralization. All p-values are FDR-corrected (Benjamini-Hochberg, q < 0.05). CON = controls, DYS = adults with developmental dyslexia.

Region	CON M (SD)	DYS M (SD)	t(68)	p (one-tailed)	d
Composite LI	0.659 (0.062)	0.627 (0.132)	1.32	0.095	0.32
Broca's area	0.662 (0.079)	0.633 (0.122)	1.18	0.122	0.28
SMA	0.501 (0.163)	0.453 (0.188)	1.16	0.126	0.28
Precentral gyrus	0.659 (0.062)	0.627 (0.132)	1.32	0.095	0.32
Middle temporal gyrus	0.451 (0.211)	0.490 (0.195)	-0.81	0.790	-0.19

Note. All p-values FDR-corrected. No region reached significance (q < 0.05). CON = controls, DYS = dyslexia.

3.2 Lexical Decision Task — Orthographic Processing

Lateralization indices during the lexical decision task are summarized in Table 2 (see end of document). A significant group difference was observed for the fusiform gyrus/VWFA: controls showed significantly stronger left-hemisphere lateralization than adults with dyslexia (t(68) = 3.19, p = 0.001, d = 0.76), representing a large effect size. Controls showed a mean absolute LI of 0.539 (SD = 0.129) compared to 0.412 (SD = 0.197) in the dyslexia group. No other region reached significance after FDR correction, including Broca's area (t(68) = 1.54, p = 0.065, d = 0.37), middle temporal gyrus (t(68) = 0.85, p = 0.200, d = 0.20), inferior parietal lobule (t(68) = 0.97, p = 0.167, d = 0.23), and inferior occipital cortex (t(68) = 0.11, p = 0.457, d = 0.03).

Table 2

Lateralization Index (|LI|) Group Comparisons — Lexical Decision Task (Orthographic Processing). Values represent mean absolute lateralization index (SD). All p-values are FDR-corrected. CON = controls, DYS = adults with developmental dyslexia.

Region	CON M (SD)	DYS M (SD)	t(68)	p (one-tailed)	d
Composite LI	0.608 (0.130)	0.563 (0.146)	1.38	0.085	0.33
Broca's area	0.569 (0.162)	0.507 (0.175)	1.54	0.065	0.37
Fusiform/VWFA*	**0.539 (0.129)**	**0.412 (0.197)**	**3.19**	**0.001**	**0.76**
Middle temporal gyrus	0.551 (0.163)	0.517 (0.179)	0.85	0.200	0.20
Inferior parietal lobule	0.488 (0.214)	0.439 (0.211)	0.97	0.167	0.23
Inferior occipital cortex	0.478 (0.224)	0.473 (0.163)	0.11	0.457	0.03

*Note. All p-values FDR-corrected. Bold indicates significant result after correction. *Fusiform/VWFA: p = 0.001, d = 0.76 (large effect). CON = controls, DYS = dyslexia.*

3.3 Individual Variability in Fusiform Lateralization

Levene's test revealed that the dyslexia group showed significantly greater variability in fusiform |LI| during the lexical decision task than controls ($F(1,68) = 10.20$, $p = 0.002$; CON SD = 0.129, DYS SD = 0.197). No significant variance differences were found for any other region in either task (all $p > 0.12$). This pattern suggests that atypical fusiform lateralization in dyslexia is characterized by increased individual variability rather than a uniform directional shift across participants.

3.4 Brain-Behavior Correlations

Pearson correlations were computed between fusiform |LI| during the lexical decision task and standardized cognitive test scores across the full sample (N = 70). Fusiform lateralization was positively associated with word reading fluency (EMT; $r = 0.39$, $p = 0.001$, $n = 70$) and spelling accuracy (sp1; $r = 0.34$, $p = 0.005$, $n = 69$), and negatively associated with phonological error rate (fo3; $r = -0.32$, $p = 0.008$, $n = 70$), such that stronger left-lateralization of the VWFA was associated with better reading and spelling performance and fewer phonological errors. When examined separately within each group, none of these correlations reached significance (all $p > 0.44$), suggesting the brain-behavior relationships are driven primarily by between-group variance.

4. Discussion

The present study examined hemispheric lateralization of task-evoked activation during phonological and orthographic processing in Dutch-speaking adults with and without developmental dyslexia, constituting an independent secondary analysis of OpenNeuro dataset ds005577. The principal findings were: (1) adults with dyslexia showed significantly reduced left-hemisphere lateralization of the fusiform gyrus/VWFA during orthographic processing, with a large effect size ($d = 0.76$); (2) the dyslexia group showed significantly greater variability in fusiform lateralization than controls; (3) no significant group differences in hemispheric lateralization were observed during phonological processing; and (4) fusiform lateralization correlated significantly with word reading, spelling, and phonological accuracy across the full sample. These findings directly replicate and extend the results of Pérez-Cuesta et al. [23].

4.1 Reduced VWFA Lateralization in Dyslexia

The detection of reduced left-lateralization of the fusiform gyrus/VWFA during lexical decision is consistent with a large body of previous neuroimaging studies demonstrating VWFA compromise in developmental dyslexia. Significantly reduced activation of the left occipitotemporal cortex during reading tasks in adults with dyslexia has been reproduced across multiple studies [13, 14, 18]. The current lateralization analysis extends this picture by demonstrating that the group difference reflects a relative atypicality in hemispheric organization — manifested as reduced left-hemisphere dominance of the fusiform gyrus in adults with dyslexia.

The VWFA is believed to emerge through reading experience as a region specialized for invariant, position-independent recognition of word forms [17, 16]. Left-hemisphere specialization of this region is recognized as a hallmark of skilled reading, developing gradually through literacy acquisition. The decreased left lateralization observed in the current sample may indicate a failure to develop normal hemispheric specialization, possibly associated with impaired phonological processing that disrupts formation of stable orthographic representations [25, 26]. An alternative interpretation is that reduced VWFA lateralization reflects compensatory activation of the right-hemisphere occipitotemporal cortex, associated with whole-word or configural reading strategies in dyslexic readers [12, 22].

4.2 Greater Variability in Dyslexia

The dyslexia group showed significantly greater inter-individual variability in fusiform lateralization (Levene's $F = 10.20$, $p = 0.002$), aligning with the interpretation offered by Pérez-Cuesta et al. [23] that lateralization in dyslexia is inconsistent rather than uniformly reduced. The high within-group variance (DYS SD = 0.197, CON SD = 0.129) suggests that some adults with dyslexia showed lateralization patterns comparable to controls, while others demonstrated markedly atypical or absent lateralization. This heterogeneity has important implications for neuroimaging studies of dyslexia, as group-level comparisons may underestimate the prevalence and severity of VWFA atypicalities.

4.3 Absence of Group Differences During Phonological Processing

The absence of significant group differences in hemispheric lateralization during the rhyme decision task is a notable finding. Both groups showed near-universal left-hemisphere dominance during phonological processing, with 100% of controls and 94% of dyslexic adults classified as left-lateralized. This null result is consistent with prior studies reporting broadly preserved phonological processing lateralization in dyslexia by adulthood [19, 27], and replicates the findings of Pérez-Cuesta et al. [23] for this dataset. One possibility is that by adulthood, individuals with dyslexia have developed sufficient compensatory phonological strategies resulting in broadly normal lateralization patterns during explicit phonological judgment tasks.

4.4 Brain-Behavior Correlations

The finding that stronger fusiform lateralization was associated with better word reading fluency ($r = 0.39$), spelling ($r = 0.34$), and phonological accuracy ($r = -0.32$) across the full sample provides direct evidence linking individual differences in VWFA hemispheric specialization to reading-related cognitive performance. This pattern is consistent with theoretical accounts proposing that left-hemisphere specialization of the VWFA supports efficient orthographic processing and that reduced specialization is associated with less fluent reading [17, 16]. The absence of significant within-group correlations suggests that these relationships are driven primarily by between-group variance, reflecting broader differences between typical and dyslexic readers rather than individual variability within each group.

4.5 Specificity of Orthographic Processing Deficits

The overall pattern of substantial VWFA lateralization reduction during orthographic processing, with no corresponding difference during phonological processing, suggests that the neural signature of orthographic processing impairment is dissociable from phonological processing in developmental dyslexia. This aligns with dual-route theories of reading [28] and observations that reading fluency deficits in adults with dyslexia may be more closely related to orthographic than phonological processing [29, 30]. The VWFA finding is also concordant with the neuronal recycling hypothesis [17], suggesting that VWFA specialization represents a culturally acquired neural adaptation to literacy, the development of which is disrupted in dyslexia.

4.6 Limitations

Several limitations should be noted. First, this is a secondary analysis of publicly available data; no independent preprocessing of raw images was conducted, and results should be interpreted in the context of the original preprocessing pipeline and GLM. Second, because the same sample is used, the present findings necessarily replicate rather than independently confirm those of Pérez-Cuesta et al. [23]. Third, the sample size (N = 35 per group) may limit statistical power for detecting smaller effects in other regions of interest. Fourth, the static threshold LI method employed may not fully capture gradual hemispheric asymmetries; bootstrap-based LI methods are considered more robust. Fifth, no within-group brain-behavior correlations reached statistical significance, limiting conclusions about individual variability within the dyslexia and control groups specifically. Finally, the sample comprised exclusively Dutch-speaking adults, limiting generalizability to other language groups and developmental periods.

5. Conclusions

This study provides an independent replication of reduced left-hemisphere lateralization of the VWFA during orthographic processing in adults with developmental dyslexia, with a large and statistically robust effect (d = 0.76). This atypicality is selective to orthographic processing demands and does not extend to phonological processing, suggesting a region-specific rather than global disruption of hemispheric organization in dyslexia. Adults with dyslexia additionally demonstrated significantly greater variability in VWFA lateralization, and individual differences in fusiform asymmetry correlated meaningfully with reading and spelling performance across the full sample. These results are consistent with the VWFA deficit hypothesis of developmental dyslexia, replicate the findings of Pérez-Cuesta et al. [23], and highlight the importance of examining both the magnitude and variability of hemispheric specialization in neuroimaging studies of reading disorders. Future research should investigate these patterns in larger, cross-linguistic samples and employ more robust lateralization methods to further characterize the heterogeneity of VWFA organization in dyslexia.

Declarations

Ethics Approval and Consent to Participate

The original data collection for OpenNeuro dataset ds005577 was approved by medical ethical committee of Ghent University Hospital under approval number BC-09822. All participants provided written informed consent in accordance with the Declaration of Helsinki. As a secondary analysis of publicly available de-identified data, no additional ethics approval was required for the present study.

Conflict of Interest

The authors declare no conflict of interest.

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Author Contribution

H.F. conceptualized the study, conducted data curation, formal analysis, and statistical methodology, developed the analysis software, prepared all visualizations, and wrote the original manuscript draft. M.F. contributed to conceptualization, manuscript writing, review, and editing, and provided overall supervision. M.R. contributed to data analysis, review, and editing, and provided supervision. All authors reviewed and approved the final manuscript.

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Data Availability

The data analyzed in this study are publicly available in the OpenNeuro repository under dataset identifier ds005577 (https://openneuro.org/datasets/ds005577). No new data were generated. Analysis code is available from the corresponding author upon reasonable request.

All statistical values are derived from analysis of OpenNeuro dataset ds005577 (https://openneuro.org/datasets/ds005577). Full analysis script and data are available at the OSF repository (https://osf.io/d8e9b/).

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31. All statistical values are derived from analysis of OpenNeuro dataset ds005577 (https://openneuro.org/datasets/ds005577). Full analysis script and data are available at the OSF

repository (https://osf.io/d8e9b/).

Figures

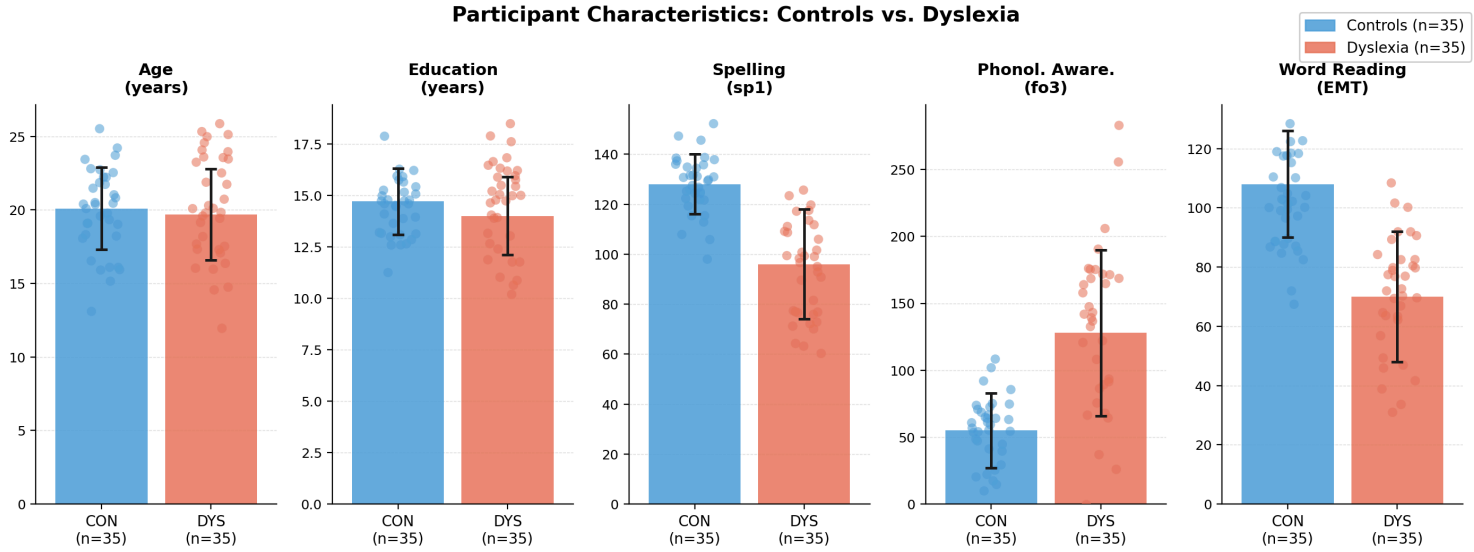


Figure 1

Participant characteristics. Group distributions for controls (blue) and adults with dyslexia (red). Error bars represent ±1 SD.

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Figure 2

Anatomical locations of regions of interest (ROIs) in the left hemisphere, shown in sagittal, coronal, and axial views (MNI coordinates).

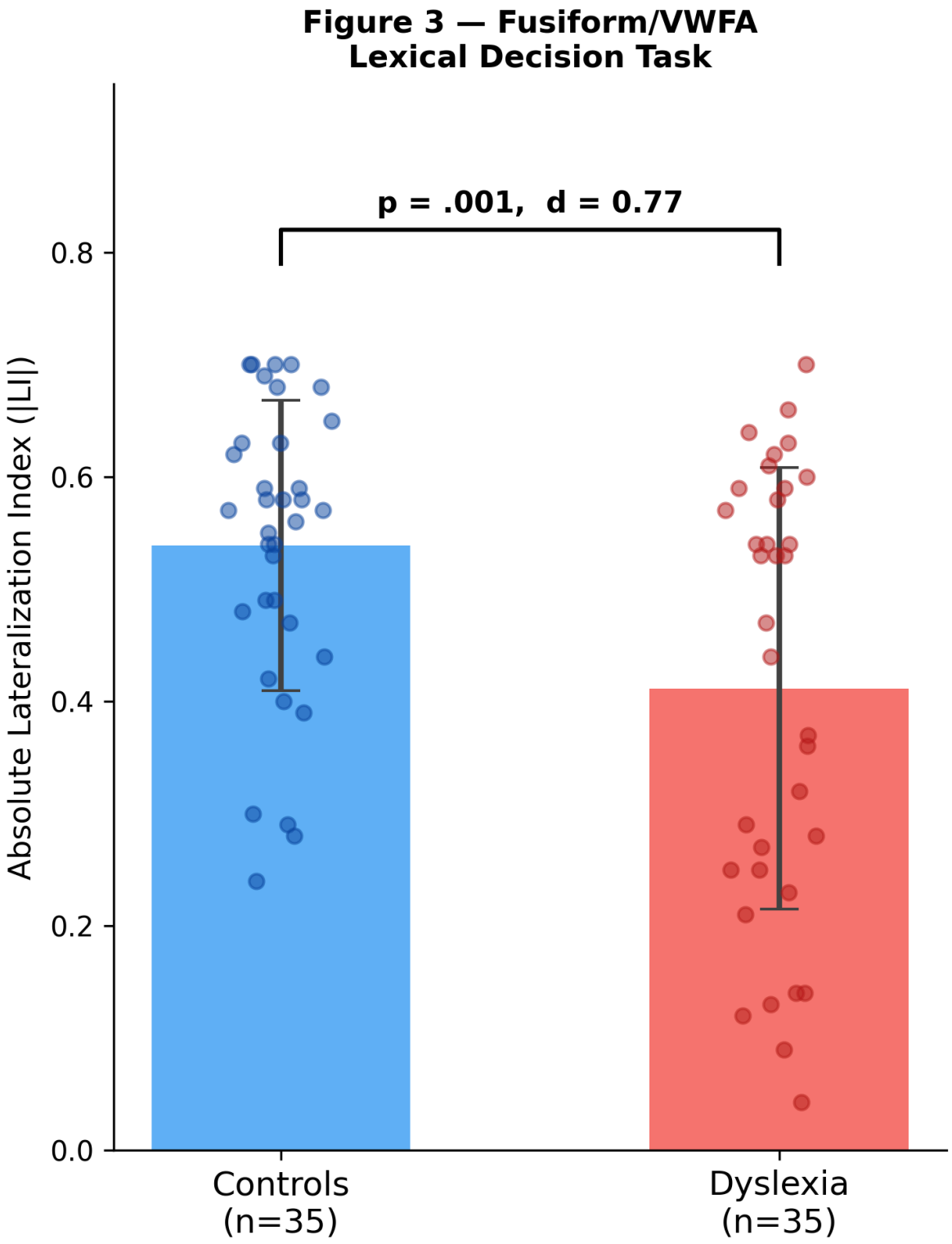


Figure 3

Absolute Lateralization Index (|LI|) for the Fusiform/VWFA during the Lexical Decision Task. Controls (blue) show significantly stronger left-lateralization than the dyslexia group (red; p = .001, d = 0.76). Individual data points are overlaid on group mean bars (±1 SD).

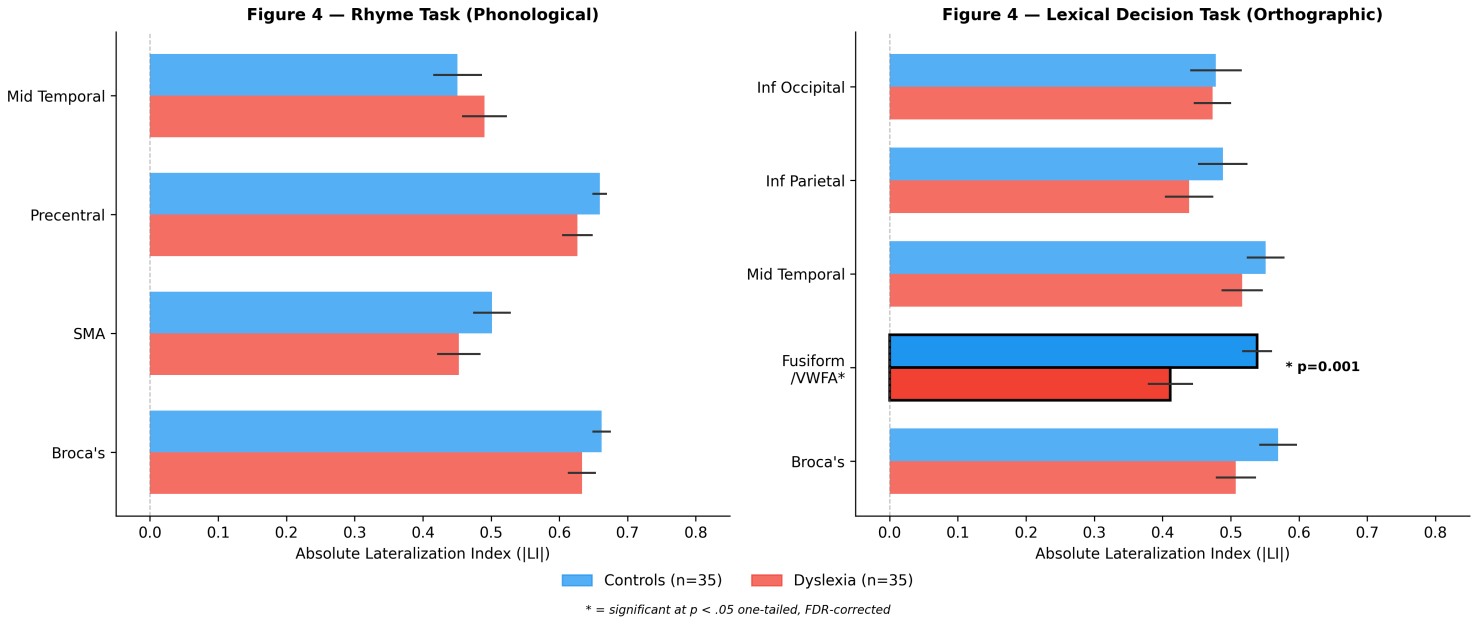


Figure 4

*Absolute Lateralization Index (|LI|) across all ROIs for the Rhyme Task (phonological; left panel) and Lexical Decision Task (orthographic; right panel). The Fusiform/VWFA showed a significant group difference during the Lexical Decision Task (*p = 0.001, FDR-corrected). Error bars = ±1 SEM.*

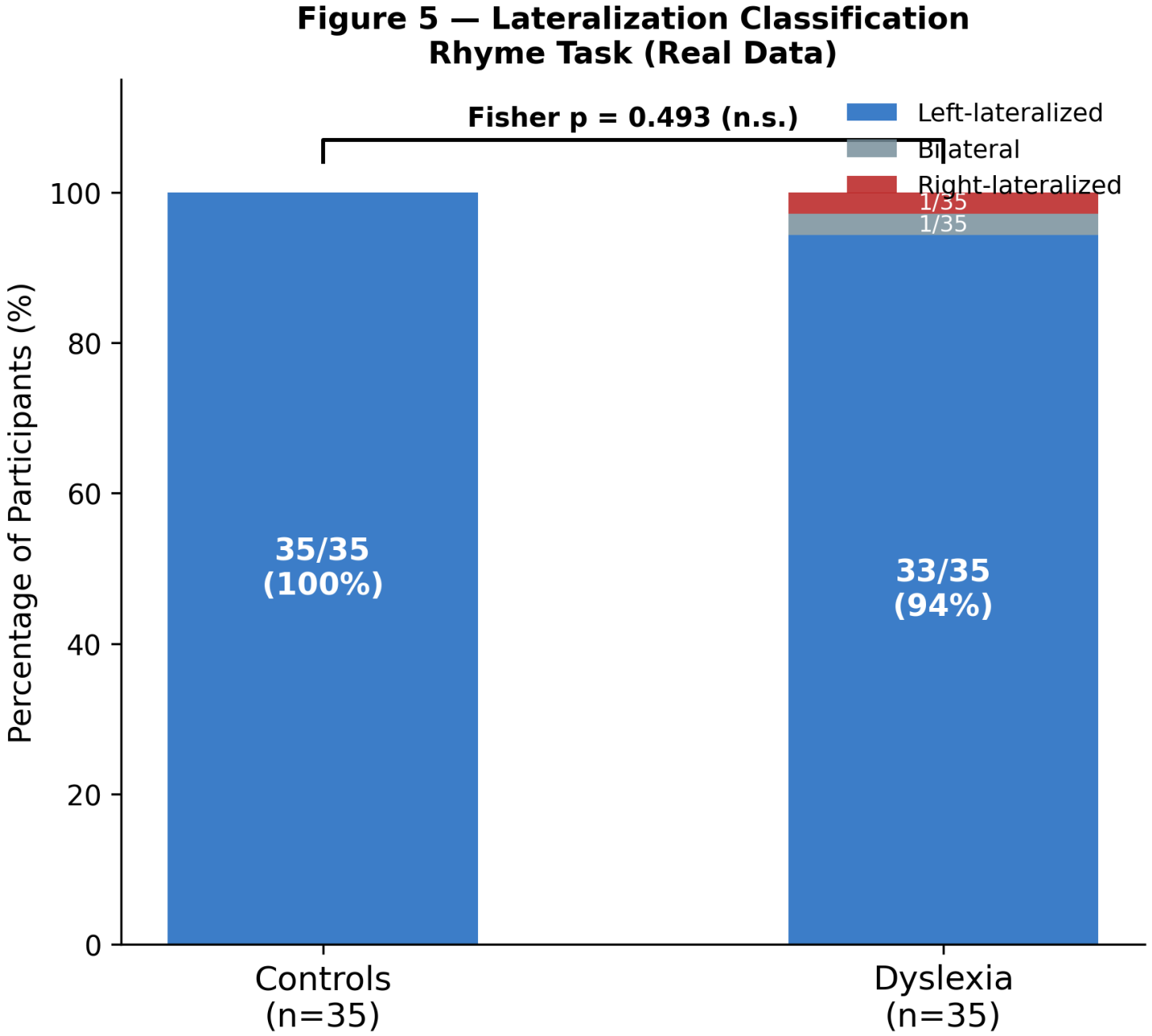


Figure 5

Lateralization classification during the Rhyme Task. The vast majority of participants in both groups were left-lateralized (Fisher's exact p = 0.493, n.s.).